

## INPUT CIRCUIT AND OUTPUT CIRCUIT

### BACKGROUND OF THE INVENTION

The present invention relates to input circuit and output circuit for transferring data within a semiconductor integrated circuit at a much higher speed.

As the multimedia applications have been expanding in recent years, improvement of operating performance of a semiconductor device has become more and more pressing task to be fulfilled. That is to say, an ideal operating speed of a semiconductor device has been steeply rising, and desired power consumption of the device has been drastically falling. In particular, a system, like an image processor, which is intended to process a large quantity of data at a high speed, strongly needs a semiconductor device operative at an extremely high speed. Generally speaking, in order to operate a device at a high speed, data should be transferred within the device at a high speed, which in turn requires some high-speed data transfer technique. High-speed-transfer-related technology includes speeding up the operation of an input/output circuit and adopting a high-speed transfer standard for a data bus. Also, input circuits of various types have become popular lately. Examples of those circuits include: a differential input circuit for comparing a voltage of a signal received to a reference voltage and amplifying the voltage of

the received signal based on the difference therebetween; and a differential input circuit for receiving differential (or complementary) signals and outputting a single signal.

If an output circuit for outputting a data signal has a push-pull configuration, however, it is very difficult to match its output impedance, or its output current, when each driver transistor outputs H-level data with its output impedance or current when each transistor outputs L-level data. In this specification, "L-level data" and "H-level" data means data with a voltage level defined as logically low (i.e., the voltage level is lower than a certain reference level) and data with a voltage level defined as logically high (i.e., the voltage level is higher than the reference level), respectively. Also, if an output circuit for outputting a data signal is a pull-up output circuit including a pull-up resistor connected to the output thereof, it is hard to equalize a current flowing through the resistor with that flowing through a transistor for outputting the data signal.

In view of the state of the art, the length of a transition interval from L to H level of a data signal is not equal to that of its transition interval from H to L level. Thus, an interval during which the voltage level of such a data signal received by a receiver is defined as logically high judging from the reference voltage is not equal in length to an interval during which that of the data signal is defined

as logically low. If such a data signal is transferred and held at irregular intervals in response to a clock signal with regular pulses, then skewing is more likely to happen. As a result, the receiver might operate erroneously, thus interfering with the speedup of a system. The higher the intended speed of a system is, the more seriously such skewing is affecting. In general, the length of a data transition interval is on the orders of several hundreds picoseconds to several nanoseconds. Thus, if a high-speed operation should be performed responsive to a clock signal at a frequency of several hundreds megahertz (i.e., one cycle of the clock signal is several nanoseconds), then the data transition intervals account for as much as several tens percent of one cycle of the clock signal. Thus, skewing is very likely to happen in such a situation.

## SUMMARY OF THE INVENTION

An object of the present invention is providing input and output circuits contributing to a high-speed operation by suppressing skewing, resulting from a difference in length between the transition interval of an input data signal from H to L level and its transition interval from L to H level.

In the input circuit of the present invention, to correct such a difference in length between these two types of transition intervals of a data signal received, a clock sig-

nal is delayed based on at least one of these two transition intervals of the data signal. And the received data signal is latched using at least one of these two types of delayed clock signals and/or the original clock signal.

5 Also, to correct such a difference in length between these two transition intervals of a data signal to be transmitted, the output circuit of the present invention is adapted to control the drivability of a driver thereof outputting the data signal.

10 Specifically, an input circuit according to the present invention includes: delay means for defining a delay time for at least one logical state of a data signal and thereby delaying the clock signal for the delay time defined; and a holding circuit for holding the data signal responsive to the  
15 delayed clock signal.

In one embodiment of the present invention, the delay means preferably defines the delay time such that an edge of the clock signal, on which the data signal is intended to be latched and which is included within a transition interval of  
20 the data signal, is delayed to a point in time after the transition interval of the data signal is over.

In this particular embodiment, the delay means may include: a comparator for comparing the edge of the clock signal, on which the data signal is intended to be latched, to  
25 at least one of leading and trailing edges of the data sig-

nal; and a delay circuit for defining the delay time based on a result of comparison performed by the comparator.

In an alternate embodiment, the delay means may include: a comparator for comparing the edge of the clock signal, on which the data signal is intended to be latched, to leading and trailing edges of the data signal; a first delay circuit for defining the delay time for a logically high state of the data signal based on a result of comparison, performed by the comparator, between one of the leading edges of the data signal and the edge of the clock signal; a second delay circuit for defining the delay time for a logically low state of the data signal based on a result of comparison, performed by the comparator, between one of the trailing edges of the data signal and the edge of the clock signal; and a selector for selecting the delay time defined by the first delay circuit when the data signal is in the logically high state or the delay time defined by the second delay circuit when the data signal is in the logically low state.

In another embodiment, the delay circuit may define the delay time based on the result of comparison performed by the comparator and a setup time for correctly latching the data signal.

An output circuit according to the present invention includes: a driver including a plurality of devices outputting a data signal, the total drivability of the devices being

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controllable; and a controller, responsive to a signal representing a transition interval length of the data signal, for increasing or decreasing the drivability of the driver.

In one embodiment of the present invention, the controller preferably receives the signal, representing the transition interval length of the data signal, from an input circuit to which the data signal is output from the output circuit.

The input circuit of the present invention can prevent erroneous latching. For example, suppose the transition interval of a data signal from H into L level is relatively long. In such a case, even though an edge of the original clock signal, on which the data signal is usually latched, is included within the transition interval, the original clock signal is delayed for a relatively long amount of time defined for the logically state of the data signal. Accordingly, an edge of the delayed clock signal, on which the data signal is actually latched, is located at a point in time after the transition of the data signal into the L level is over. As a result, the L-level data signal can be latched correctly with a lot more certainty.

The output circuit of the present invention can also prevent erroneous latching. For example, suppose the transition interval of a data signal from H into L level is relatively long. In such a case, even though an edge of the

clock signal, on which the data signal is usually latched, is included within the transition interval, the transition interval can be shortened, because the drivability of the driver is increased. Thus, the edge of the clock signal, on which the data signal is actually latched, is located at a point in time after the shortened transition interval of the data signal into the L level is over. As a result, the L-level data signal can be latched correctly with a lot more certainty.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram illustrating an internal configuration of an input circuit according to a first embodiment of the present invention.

Figure 2(a) is a timing diagram illustrating a test-mode operation of the input circuit of the first embodiment; and

Figure 2(b) is a timing diagram illustrating a normal-mode operation of the input circuit of the first embodiment.

Figure 3 is a block diagram illustrating a schematic arrangement of a data signal transmitting/receiving system including transmitter and receiver chips according to the first embodiment.

Figure 4 is a block diagram illustrating an internal configuration of the receiver chip.

Figure 5 is a block diagram illustrating a schematic arrangement of a data signal transmitting/receiving system in-

cluding transmitter and receiver chips according to a second embodiment of the present invention.

Figure 6 is a timing diagram how erroneous latching happens when the transition interval of a data signal from H in-  
5 to L level is long.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, preferred embodiments of the present invention will be described with reference to the accompanying  
10 drawings.

##### EMBODIMENT 1

Figures 1, 2, 3 and 4 illustrate a first exemplary embodiment of the present invention. Figure 3 illustrates an  
15 overall arrangement of a data signal transmitting/receiving system including transmitter and receiver chips.

As shown in Figure 3, the transmitter chip 10 includes a plurality of, or a number  $n$  of, output buffers 301, 302, ..., 30 $n$  and an internal circuit 35. The internal circuit 35  
20 sends out a mode-switching signal  $Con$  for switching a test mode into a normal operation mode, or vice versa, and data signals  $D1$ ,  $D2$ , ...,  $Dn$  to the receiver chip 20 via these output buffers 301 through 30 $n$ .

As shown in Figures 3 and 4, the receiver chip 20 in-  
25 cludes: a number  $n$  of input circuits 401, 402, ..., 40 $n$ ; an in-



ternal circuit 50; a phase locked loop (PLL) circuit 51; and a power supply circuit 52. The input circuits 401 through 40n respectively hold the data signals D1, D2, ..., Dn received. The data signals D1'', D2'', ..., Dn'', which are held in these  
5 input circuits 401 through 40n, are then supplied to the internal circuit 50. Responsive to a reference clock signal, the PLL circuit 51 generates a clock signal CLK and supplies the clock signal CLK to the internal circuit 50. The power supply circuit 52 supplies a power supply voltage to the internal circuit 50 and a reference voltage Vref (described  
10 later) to the respective input circuits 401 through 40n.

Figure 1 illustrates an internal configuration of the input circuit 401. It should be noted that the other input circuits 402 through 40n also have the same configuration as  
15 that of the input circuit 401 shown in Figure 1.

As shown in Figure 1, the input circuit 401 includes: an input buffer 11; a delay section 60; and a holding circuit 21. The delay section 60 includes: a comparator 5; two delay circuits 31 and 32; and a selector 4.

20 The input buffer 11 is a differential amplifier (differential input device), which receives the reference voltage Vref and the data signal D1 and outputs an amplified signal D1' based on the difference between the voltage of the data signal D1 and the reference voltage Vref. The reference  
25 voltage Vref is set equal to or lower than the power supply

voltage and higher than a ground potential. If the voltage of the input signal **D1** is higher than the reference voltage **Vref**, then the input buffer **11** outputs the power supply voltage as the "H-level" potential (i.e., logically high voltage).

5 Alternatively, if the voltage of the input signal **D1** is lower than the reference voltage **Vref**, then the input buffer **11** outputs the ground potential as the "L-level" potential (i.e., logically low voltage).

The holding circuit **21** is implemented as a D-latch,  
10 which holds the amplified data signal **D1'** supplied from the input buffer **11** in synchronism with a leading edge of a clock signal **CLK2** delayed by the delay circuit **31** or **32**, and then outputs latched data signal **D1''**. That leading edge of the delayed clock signal **CLK2** is equivalent to the edge on which  
15 the data signal is latched as defined in the appended claims.

The comparator **5** compares the phase of the amplified data signal **D1'** to that of the clock signal **CLK**. The result of phase comparison between a leading edge of the data signal **D1'** (i.e., transition from L into H level) and a corresponding leading edge of the clock signal **CLK** is output as a signal **CdelF** or **CdelB**. If the leading edge of the data signal **D1'** is prior to that of the clock signal **CLK**, then a pulse with a width equal to the phase difference therebetween is output as the signal **CdelF**. Conversely, if the leading edge  
20 of the data signal **D1'** is posterior to that of the clock sig-  
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nal **CLK**, then a pulse with a width equal to the phase difference therebetween is output as the signal **Cde1B**. Similarly, the result of phase comparison between a trailing edge of the data signal **D1'** (i.e., transition from H into L level) and an associated leading edge of the clock signal **CLK** is output as a signal **Cde2F** or **Cde2B**. If the trailing edge of the data signal **D1'** is prior to the leading edge of the clock signal **CLK**, then a pulse with a width equal to the phase difference therebetween is output as the signal **Cde2F**. Conversely, if the trailing edge of the data signal **D1'** is posterior to the leading edge of the clock signal **CLK**, then a pulse with a width equal to the phase difference therebetween is output as the signal **Cde2B**.

The delay circuits 31 and 32 can delay the clock signal CLK for respective amounts of time variable with the results of phase comparison represented by the signals Cde1F/Cde1B and Cde2F/Cde2B received from the comparator 5. The first delay circuit 31 outputs a delayed clock signal CLK\_LH derived by delaying the clock signal CLK for the amount of time determined by the signal Cde1F or Cde1B. Similarly, the second delay circuit 32 outputs a delayed clock signal CLK\_HL derived by delaying the clock signal CLK for the amount of time determined by the signal Cde2F or Cde2B. The delay circuits 31 and 32 and the comparator 5 are activated while the mode-switching signal Con is high, but are deactivated while

the mode-switching signal **Con** is low.

If the data signal **D1'** is logically high, then the selector 4 selects the signal **CLK\_LH** output from the delay circuit 31. Alternatively, if the data signal **D1'** is logically low, then the selector 4 selects the signal **CLK\_HL** output from the delay circuit 32. Then, the selector 4 outputs the selected signal **CLK\_LH** or **CLK\_HL** as the clock signal **CLK2** to the holding circuit 21.

Next, the operation of the input circuit of the present invention will be described separately in terms of test and normal operation modes thereof.

Figures 2(a) and 2(b) are timing diagrams illustrating the operation of the input circuit in the test mode and the normal operation mode, respectively.

(Test mode)

First, a test mode interval (initializing interval) is provided to determine the respective amounts of time for which the clock signal **CLK** should be delayed.

When the signal **Con** reaches the H level, the initializing interval starts. At the outset of the initializing interval, the data signal **Data**, which repeatedly alternates its level between H and L, is output as test data from the transmitter chip 10 to the receiver chip 20. As shown in Figure 2(a), the length of the transition interval of the data sig-

nal D1 from L into H is different from that of the transition interval of the data signal D1 from H into L. Accordingly, the length of an interval during which the data signal D1' amplified by the input buffer 11 is high is not equal that of  
5 an interval during which the signal D1' is low.

In this embodiment, in holding the data signal D1' responsive to a clock signal, a setup time T1 of a sufficient length is determined in advance, which accounts for about 30% to about 50% of one cycle of the clock signal. Also, this  
10 setup time T1 is a relatively long period of time, which is longer than phase difference T2 or T3 described below. Suppose a leading edge of the data signal D1' turns out to be prior to an associated leading edge of the clock signal CLK as a result of phase comparison between the data signal D1'  
15 and the clock signal CLK by the comparator 5. Then, the delay circuit 31 determines the delay time del as  $T1 - T2$ , where T2 is a phase difference between these leading edges of the data signal D1' and the clock signal CLK. On the other hand, if a leading edge of the data signal D1' turns out to be posterior to an associated leading edge of the clock signal CLK,  
20 then the delay circuit 31 determines the delay time del as  $T1 + T2$ . Moreover, suppose a trailing edge of the data signal D1' turns out to be posterior to an associated leading edge of the clock signal CLK. Then, the delay circuit 32 determines the delay time de2 as  $T1 + T3$ , where T3 is a phase dif-  
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ference between the trailing edge of the data signal **D1'** and the leading edge of the clock signal **CLK**. Furthermore, if a trailing edge of the data signal **D1'** turns out to be prior to an associated leading edge of the clock signal **CLK**, then the delay circuit 32 determines the delay time **de2** as  $T1 - T3$ . Accordingly, each leading edge of the delayed clock signal **CLK2** is always delayed from its associated leading or trailing edge of the data signal **D1'** for the setup time **T1**.

Once the delay time has been determined by the delay circuit 31 or 32 in this manner, the delay circuit 31 or 32 delays the clock signal **CLK** for the determined amount of time, thereby outputting the delayed clock signal **CLK\_LH** or **CLK\_HL**. Specifically, one delayed clock signal **CLK\_LH** is obtained by having the clock signal **CLK** delayed by the first delay circuit 31. The delay time thereof is determined based on the phase difference between a leading edge of the data signal **D1'** and an associated leading edge of the clock signal **CLK** during the transition of the data signal **D1'** from L into H level. On the other hand, the other delayed clock signal **CLK\_HL** is obtained by having the clock signal **CLK** delayed by the second delay circuit 32. The delay time thereof is determined based on the phase difference between a trailing edge of the data signal **D1'** and an associated leading edge of the clock signal **CLK** during the transition of the data signal **D1'** from H into L level.

The initializing interval terminates when this timing control is completed.

(Normal operation mode)

5       Next, when the mode-switching signal **Con** falls to the L level, the input circuit enters the normal operation mode.

10       In this operation mode, a data signal is transferred as in an ordinary data transfer operation. The operation of holding a data signal in the holding circuit **21**, however, is performed responsive to a delayed clock signal **CLK2**, which is selected from the two delayed clock signals **CLK\_HL** and **CLK\_LH** derived during the initializing interval. The selector **4** selects one of the delayed clock signals **CLK\_HL** and **CLK\_LH** based on the logical state of the data signal **D1'**. Specifically, if the data signal **D1'** is currently logically high, then the selector **4** selects the signal **CLK\_LH**. Alternatively, if the data signal **D1'** is logically low, then the selector **4** selects the signal **CLK\_HL**. The signal selected by the selector **4** is supplied as the delayed clock signal **CLK2** to the holding circuit **21**, which holds the data signal **D1'** in synchronism with the leading edge of the delayed clock signal **CLK2**.

25       By reducing a phase difference between a leading or trailing edge of the data signal **D1'** and an associated leading edge of the delayed clock signal **CLK2** in this manner, the

data signal  $D1'$  can be held correctly and erroneous latching can be prevented.

Next, the operation of the input circuit of the present invention as shown in Figure 2 and that of a conventional circuit, in which data is latched on every leading edge of an input clock signal  $CLK$  without using the selector 4 as shown in Figure 6, will be described in comparison. As shown in Figures 2 and 6, at a time  $t_0$  synchronous with the first leading edge of the clock signal  $CLK$ , the data signal  $D1'$ , supplied from the differential amplifier 11, has a voltage higher than the reference voltage  $V_{ref}$ , and is logically high. Thus, in Figure 6, if the data signal  $D1'$  is latched on the first leading edge of the clock signal  $CLK$ , then the data signal  $D1''$  is correctly latched in the holding circuit 21 as logically high. In Figure 2, the data signal  $D1'$  is latched on the first leading edge of the delayed clock signal  $CLK_{LH}$ , which is delayed from that of the clock signal  $CLK$  for a time  $T1-T2$ . However, the data signal  $D1'$  in the logically high state may be correctly latched on the first leading edge of the input clock signal  $CLK$  as in Figure 6. Thus, according to the present invention, two kinds of delay times, corresponding to the two logical states of the data signal  $D1'$  (i.e., H and L levels), do not always have to be calculated. That is to say, according to the present invention, only one of the delayed clock signals  $CLK_{LH}$  or  $CLK_{HL}$  may be selec-



5 tively produced for one of these two logical states. Responsive to this delayed clock signal, the data signal  $D1'$  in one of the two logical states may be latched. But the data signal  $D1'$  in the other logical state may be latched responsive to the original clock signal  $CLK$  without calculating the delay time for the other logical state. In such a case, the selector 4 receives the clock signal  $CLK_{LH}$  or  $CLK_{HL}$  delayed by one of the two delay circuits (e.g., 31) and the original clock signal  $CLK$ .

10 According to the present invention, the setup time  $T1$  does not always have to be provided. However, in order to latch the data signal  $D1'$  during a steady-state interval (in which the voltage is constant) after the transition interval of the data signal  $D1'$  is over, the setup time  $T1$  should preferably be provided.

Next, at a time  $t1$  synchronous with the next leading edge of the clock signal  $CLK$ , the data signal  $D1'$  supplied from the differential amplifier 11 is in the middle of level transition, but still has a voltage higher than the reference voltage  $V_{ref}$ .

20 That is to say, the data signal  $D1'$  is logically high at the time  $t1$  in both Figures 2 and 6. Thus, in Figure 6, if the data signal  $D1'$  is latched at the time  $t1$  synchronous with the second leading edge of the clock signal  $CLK$ , the holding circuit 21 holds the H-level data signal  $D1'$ , not the correct L-level data signal  $D1'$  as indicated by the broken line. As a

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result, erroneous data is latched. In contrast, in this embodiment, the L-level data signal **D1'** is latched correctly by the holding circuit **21** at a time **t2** synchronous with the leading edge of the delayed clock signal **CLK\_HL** obtained by delaying the clock signal **CLK** for the predetermined amount of time **de2** ( $= T1+T3$ ) as shown in Figure 2. That is to say, the data signal **D1'** is latched after the voltage of the data signal **D1'** has fallen to be lower than the reference voltage **Vref**. As a result, the present invention can prevent erroneous latching.

In this embodiment, the data signal **D1'** is supposed to be in the same logical state during one cycle of the clock signal, i.e., the frequency of the data signal is supposed to be one half as high as that of the clock signal. However, the application of the present invention is not limited to such a situation. Thus, the applicable frequencies of the data and clock signals are not particularly limited according to the present invention.

In the foregoing embodiment, the data signal **D1'** is supposed to be latched on the leading edges of the clock signal. Alternatively, the data signal may also be latched either on the trailing edges of the clock signal or on the leading and trailing edges thereof in combination.

Furthermore, in the foregoing embodiment, the first or second delay circuit **31** or **32** is selectively used. Specifically, the clock signal delayed by the first delay circuit **31**





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age level of the data signal **D1** into high, and three n-channel transistors **TN1**, **TN2** and **TN3** grounded for turning the logical voltage level of the data signal **D1** into low. The transmitter chip **70** further includes first and second controllers **72** and **73** for controlling the p-channel transistors **TP1**, **TP2** and **TP3** and n-channel transistors **TN1**, **TN2** and **TN3**, respectively. The first controller **72** receives the signal **Cde1F** or **Cde1B** representing the result of comparison between a leading edge of the data signal **D1'** and an associated leading edge of the clock signal **CLK**, i.e., the signals representing the length of the transition interval of the data signal, from the comparator **5** in the input circuit **81**. On the other hand, the second controller **73** receives the signal **Cde2F** or **Cde2B** representing the result of comparison between a trailing edge of the data signal **D1'** and an associated leading edge of the clock signal **CLK**, from the comparator **5** in the input circuit **81**. These signals **Cde1F/Cde1B** and **Cde2F/Cde2B** are shown in Figure 2. Suppose the signal **Cde1B** is supplied to the first controller **72**, i.e., the time when the voltage of the data signal **D1'** rises to reach the reference voltage **Vref** is later than the leading edge of the clock signal **CLK** during the transition of the data signal **D1'** from L to H level. In other words, if the transition interval is relatively long, then the first controller **72** increases the number of p-channel transistors to be turned ON, thereby en-

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hancing the total drivability of the output buffer 71 to shorten the transition interval. On the other hand, suppose the signal **Cde2B** is supplied to the second controller 73, i.e., the time when the voltage of the data signal **D1'** drops to reach the reference voltage **Vref** is later than the leading edge of the clock signal **CLK** during the transition of the data signal **D1'** from H to L level. In other words, if the transition interval is relatively long, then the second controller 73 also increases the number of n-channel transistors to be turned ON, thereby enhancing the total drivability of the output buffer to shorten the transition interval.

The data signal **D1'** is fed back to the first and second controllers 72 and 73. Accordingly, even if these controllers 72 and 73 do not receive the signals **Cde1F/Cde1B** and **Cde2F/Cde2B** from the comparator 5, the drivability of the output buffer 71 can be known based on the feedback signal. And if the drivability is low, the number of transistors to be turned ON may be increased.

Accordingly, in this embodiment, the drivability of the output buffer 71 can be controlled on the transmitting end, i.e., in the transmitter chip 70, thereby adjusting the length of the transition interval of the data signal **D1'** from H into L level or vice versa. Thus, as in the first embodiment, skewing can be suppressed and a high-speed operation is ensured in a frequency region where the clock frequency is

several hundreds megahertz or more.

In the foregoing discussion, the present invention has been described as being applied to an input circuit receiving a single data signal D1'. However, the present invention is  
5 also applicable to an input circuit receiving differential input signals. In such a case, these differential signals are supplied to the differential amplifier 11.

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